THE (GARRETT) CORPORATION
AiResearch Manufacturing Division
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4 PROGRESS REPORT
RESEARCH STUDY ON INSTRUMENT UNIT
THERMAL CONDITIONING HEAT SINK CONCEPTS
APRIL 1 TO APRIL 30, 1966

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INTRODUCTION

This report reviews the work accomplished by the AiResearch Manufacturing Company, a division of The Garrett Corporation, Los Angeles, California, between April 1 and April 30, 1966, under National Aeronautics and Space Administration Contract NAS8-11291. This contract is for a research study on instrument unit thermal conditioning heat sink concepts. This report is the second monthly progress report under the referenced contract which was signed on March 11, 1966. The previous report under this contract was issued under AiResearch report number 66-0479.

PROGRESS SUMMARY

During the month of April work was concentrated in the following areas: Under Task 1, Water Boiler Heat Sink Module, a review was made of existing wick data from the Apollo evaporator program and AiResearch company sponsored work, and a partial literature review as made. A preliminary design of a wick heat transfer test apparatus was completed, and analysis of flow in capillaries was undertaken. Under Task 2, Water Sublimator Heat Sink Module, analysis was undertaken which led to preliminary design of a sublimator visualization test setup. Several different types of porous plate material were received, and design of a fixture to be used for sublimation performance testing of porous plates was reviewed for improvements to yield greater flexibility and improved data for testing on this program. A complete set of detailed test instructions for porous plate bench tests was prepared.

TASK I: WATER BOILER HEAT SINK MODULE

Review of Existing Wick Data

1. Wick Endurance Testing

AiResearch has conducted a series of 1000-hr wick performance tests as part of the Apollo glycol evaporator program. The series of tests of specific interest involved 3 in. high by 6.4 in. wide nickel feltmetal wicks of

15 percent density, with an average pore size of 0.00165 in. These wicks were heated on both sides with electrical heaters separated from the wicks by off-set rectangular fins. Four thermocouples were used to measure the plate temperatures, two adjacent to the top half of the wick, and two adjacent to the bottom half of the wick.

Five different types of tests were run. Two of the wicks were brazed as received, two were oxidized at 800°F in air and one was saturated with a 0.1 percent solution of Sterox NJ, a surface-active agent. To investigate the effect of water filtration some of the samples were fed water that had gone through a 10 micron filter, while the others were fed water that had gone through one-half micron filtration. Table I shows the results. On the basis of performance change, the best performance was obtained with the surfactant-treated wick, which actually increased 19 percent in performance over the 1000-hr test. The best overall performance of the five specimens tested was the brazed-as-received wick with one-half micron water filtration, which declined in performance only five percent. The specimens which were fed 10 micron water had performance degradations of 51 percent and 36 percent, respectively, while the oxidized wick which had one-half micron filtered water, had a performance degradation of 23 percent. While the surfactant apparently prevented any degradation and actually led to a significant increase in performance with time, the effect of the surfactant was also to decrease initial performance by a significant amount.

The following conclusions can be drawn from these 1000-hr tests.

a.   Water filtration and water purity is of great importance. Water that was filtered through a one-half micron filter led to much less degradation of wick performance than water which was filtered through a 10 micron filter.

b.   The oxidation of the nickel wicks in air leads to reduction in performance, and does not reduce susceptibility to degradation with time.

TABLE 1.   1000 HR ENDURANCE TEST RESULTS 15% DENSE NICKEL FELTMETAL WICKS

| Wick Description	Location Number		$h_{initial}$ Btu/hr ft^2 ^{o}F	h_{final} Btu/hr ft^2 ^{o}F	$\dfrac{h_{final}}{h_{initial}}$	Average Performance Change
Brazed as received 10μ water filtration	Top	1	176	106	0.60	
	Top	2	240	66	0.28	
	Bottom	1	156	91	0.58	-51%
	Bottom	2	139	71	0.51	
Brazed as received 1/2μ water filtration	Top	1	203	240	1.18	
	Top	2	240	220	0.92	
	Bottom	1	120	106	0.88	-5%
	Bottom	2	132	106	0.80	
Brazed after heating in air, 800°F, 30 min 10μ water filtration	Top	1	83	61	0.75	
	Top	2	91	45	0.49	
	Bottom	1	102	66	0.65	-36%
	Bottom	2	102	66	0.65	
Brazed after heating in air, 800°F, 30 min 1/2μ water filtration	Top	1	106	80	0.76	
	Top	2	132	132	1.00	
	Bottom	1	91	64	0.71	-23%
	Bottom	2	115	71	0.62	
Brazed as received Saturated in 0.1 percent solution of Sterox NJ. 1/2μ water filtration	Top	1	61	126	2.04	
	Top	2	115	132	1.15	
	Bottom	1	115	78	0.68	+19%
	Bottom	2	115	102	0.88	

c. Treatment of wicks with surfactant may lead to considerable reduction in susceptibility of the wick to performance degradation with time. However, the surfactant may reduce the wicking rate of the wicks significantly. An interesting possibility would be to use wicks which had an initial wicking rate considerably in excess of that required, and treat these with surfactant. Based on the results of the above tests, it might be possible to obtain immunity from performance degradation, without the sacrifice of performance that would be obtained by treating the same wick with a surface active agent.

2. Wicking Rate

The following analysis develops an equation for time it takes liquid to reach various heights in a wick after the end of a dry wick has been brought into contact with the liquid. It is assumed that there is no heat or mass transfer from the sides of the wick; the flow rate of liquid is the same as each level at any one time.

Assuming that momentum changes are negligible reduces the force balance equation to three terms: gravity, friction, and surface tension. The pressure drop due to friction is equal to the pressure drop provided by the excess of capillarity over gravity:
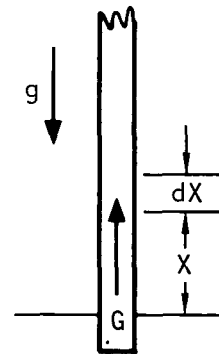
$$\frac{4\sigma \cos\theta}{D} - \frac{\rho g X}{g_0} = \frac{32\,C\,X\,\mu\,G}{\rho g_0 D^2} \tag{1}$$

The change of height with time is equal to the liquid velocity at any time. Combining this with the definition of mass velocity yields

$$G = \rho V = \rho \frac{dX}{dt} \tag{2}$$

Substituting Equation (2) into Equation (1) and solving for dt gives

$$dt = \frac{32\,\mu\,C}{g_0\,D^2} \cdot \frac{X\,dX}{\left(\frac{4\sigma\cos\theta}{D} - \frac{\rho\,g\,X}{g_0}\right)} \tag{3}$$

Integrating Equation (12) yields the final equation for the time it takes liquid to reach each height in the wick.

$$t_{g\neq o} = \frac{32\,\mu\,C}{\rho g\,D^2}\left[\frac{4\sigma\cos\theta\,g_0}{\rho g\,D}\,\log\left(\frac{1}{1 - \frac{\rho g\,D}{4\sigma\cos\theta\,g_0}}\right) - X\right] \tag{4}$$

Equation (4) shows that the time required to wick a height X is a function only of the pore diameter and fluid-surface properties. While this equation should exactly predict rise rate in a capillary, tests at AiResearch have indicated that rise rate in metal wicks is influenced by wick thickness.

One possible explanation for the effect of wick thickness on wick rate may be the surface treatment of the wick. That is, the way the wick is rolled or pressed may close or reduce in size some of the pores near the surface. If this were the reason it would mean that thicker wicks are less influenced by by thickness than thin ones, which was the case in the AiResearch studies. The capacity of the wicks to deliver water in an evaporator is a design parameter of considerable importance. This effect will be investigated in the wick performance tests.

3. Literature Review

A literature review has been started. Several reports and publications have been collected and review of these was started in April.

Wick Heat Transfer and Performance Testing

A preliminary design of a wick module performance test setup was prepared. This design will allow for testing of wicks of different thicknesses and wick height, using steam fins of varying geometry, in particular, rectangular and triangular fins. Wicks of different porosity will be tested, and the test

section will be capable of varying electrical heat input to vary heat flux. Electrical heating was selected over fluid heating for simplicity of operation, and better heat balances. The electrical heaters will be attached to a heavy copper plate so as to permit fairly exact definition of the temperature boundary conditions. The heater will be made in several vertical sections, so that the rate of heat input can be varied along the wick as would be the real situation in a wick water boiler that was removing heat from a fluid stream.

Capillary Flow Analysis

An analysis of flow in capillaries was undertaken. Rate of liquid rise and final rise height in capillary tubes are reasonably well understood. However, phenomena occurring at the boundary of both wicks and porous plates are not well enough understood to permit optimum design of hardware. Two questions of considerable importance that have not been defined as yet are (1) why does a wick filled to less than its maximum wick height drip when it is removed from a water surface and under exactly what conditions? and (2) how can bubble point and liquid breakthrough of porous plates be related to pore diameter, surface tension, and contact angle? Measurements of liquid breakthrough of porous plates in the literature have shown that the breakthrough pressure can vary from a very small fraction of the gas breakthrough pressure to a number in excess of the gas breakthrough pressure. To better understand this situation an analysis of the phenomena of breakthrough of both liquid and gas was undertaken. Figure I shows the successive steps in breakthrough or bubbling of a gas through a capillary that is initially filled with liquid. The contact angle is between zero and 45 degrees for this case. In Figure Ia the plate is shown filled with liquid but with a liquid vapor interface at the entrance to a pore. In Ib, as the pressure on the vapor is increased the interface starts to expand, maintaining the initial contact angle, until the excess vapor pressure is equal to $4\sigma \cos \theta/d$. At this point the vapor can rapidly go through the pore until it reaches the end. If the excess pressure is greater than $4\sigma \cos \theta/d$, breakthrough or bubbling will occur. The breakthrough pressure of $4\sigma \cos \theta/d$ is the familiar value that has been reported in the literature.
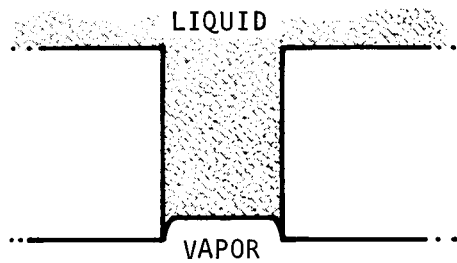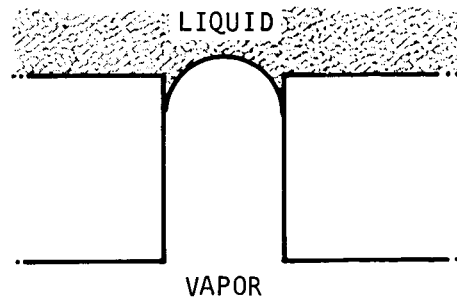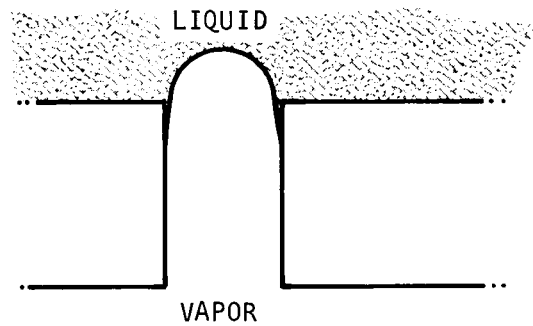
a. $P_V = P_L$
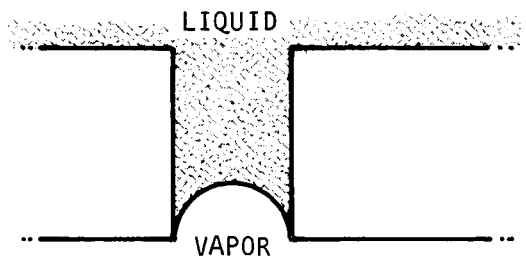
b. $P_V - P_L \le \dfrac{4\sigma \cos \theta}{D}$. INTERFACE GROWS TO SPHERICAL SHAPE.

c. $P_V - P_L = \dfrac{4\sigma \cos \theta}{D}$. VAPOR MOVES THROUGH PORE.

d. $P_V - P_L > \dfrac{4\sigma \cos \theta}{D}$. BREAKTHROUGH OCCURS.

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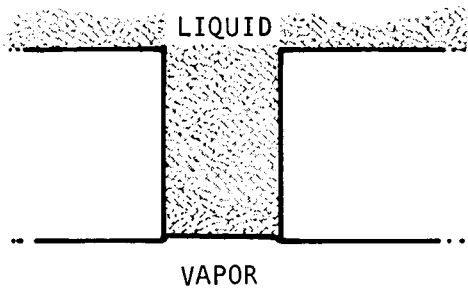Figure I.   Vapor Breakthrough Sequence
$0^0 < \theta < 45^0$

If the contact angle θ lies between 45 and 90 degrees, a different
situation, that has to our knowledge not been reported in the literature, will
occur, and the breakthrough pressure will take a considerably different value.
In Figure 2a the vapor pressure is equal to the liquid pressure and the inter-
face is just within the pore. This is the same situation as was shown in
Figure 1a, except that the contact angle is different. When the vapor pres-
sure exceeds the liquid pressure by an amount equal to $4\sigma \cos \theta/d$, the inter-
face, which has grown to a spherical shape, can proceed to the end of the pore,
as shown in Figure 2b and 2c. If the pressure is increased slightly from this
value the liquid would be expected to move out of the pore and wet the back
side of the plate, with a spherical bubble held at the pore mouth as shown in
Figure 2d. Now the surface tension force which is restraining the pressure
difference is $\sigma \sin \theta$ rather than $\sigma \cos \theta$. When the vapor pressure excess
is greater than $4\sigma \sin \theta/d$ the bubble may break off from the plate. Depending
on the contact angle, which uniquely determines the ratio of bubble diameter
to pore diameter, it is possible that the bubble may break rather than releas-
ing itself from the plate. This analysis will be continued in May. However,
the significant point which has apparently not been reported in the literature
is that the equation for the breakthrough pressure as a function of surface
tension, contact angle, and pore diameter, changes with contact angle. The
breakthrough pressure is proportional to $\cos \theta$ for contact angles less than
45 degrees, and proportional to $\sin \theta$ for contact angles between 45 degrees
and 90 degrees.

Figure 3 shows the liquid breakthrough sequence in a pore which is filled
initially with vapor. In Figure 3a the interface is shown with the liquid
pressure equal to the vapor pressure. In Figure 3b as the liquid pressure
is increased the liquid starts to flow through the pore, again maintaining the
same contact angle, and in Figure 3c the liquid is shown having turned the
corner of the pore and forming an interface on the back side of the plate. In
Figure 3c the surface tension of the liquid now restrains the flow since it
is acting in the direction opposite to the pressure difference, whereas in
Figures 3a and 3b it was acting to pull the liquid through the pore. A
force balance on the interface shows the critical breakthrough pressure to
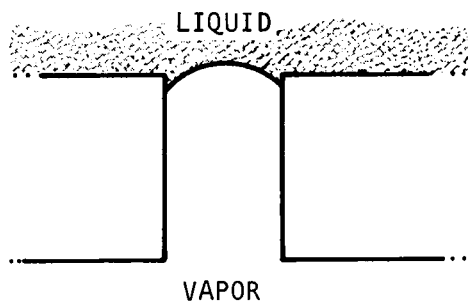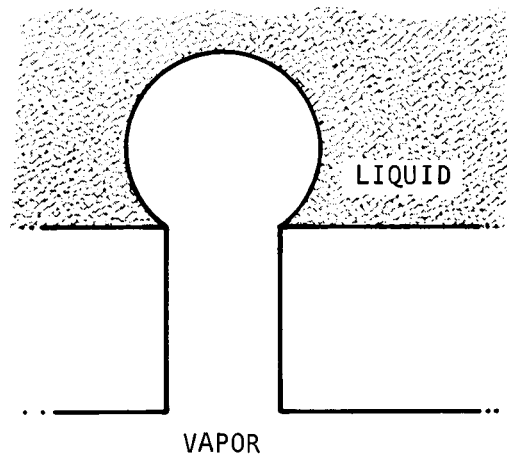be equal to $4\sigma \sin \theta/d$.

a. $P_V = P_L$
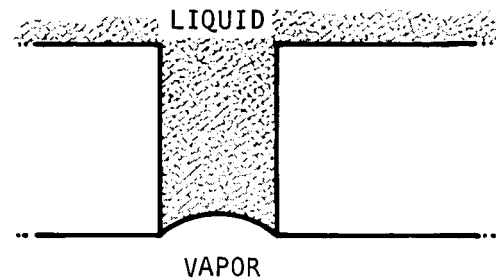
b. $P_V - P_L \leq \dfrac{4\sigma \cos \theta}{D}$. INTERFACE GROWS TO SPHERICAL SHAPE.

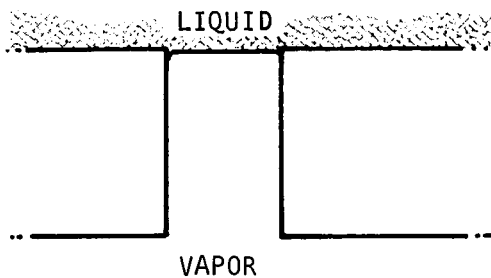c. $P_V - P_L = \dfrac{4\sigma \cos \theta}{D}$. VAPOR MOVES THROUGH PORE.

d. $P_V - P_L = \dfrac{4\sigma \sin \theta}{D}$. BUBBLE BREAKS OFF PLATE, OR FRACTURES, DEPENDING ON CONTACT ANGLE.
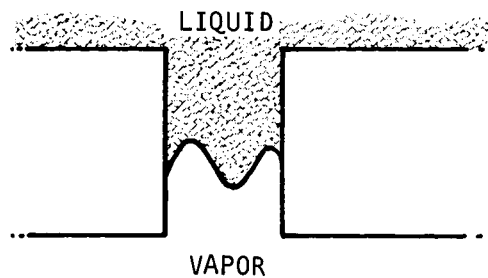
A-19948

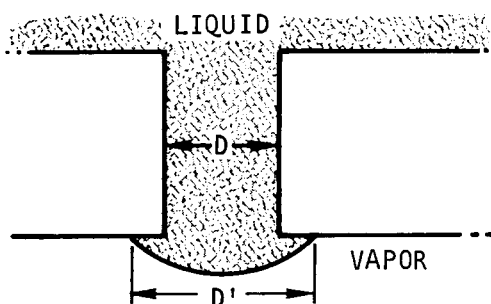Figure 2.   Vapor Breakthrough Sequence
$45^0 < \theta < 90^0$

a. $P_L = P_V$

b. $P_L > P_V$. UNSTABLE, WITH BOTH PRESSURE AND SURFACE TENSION ACTING IN THE SAME DIRECTION.

c. SURFACE TENSION NOW RESTRAINS FLOW.

$$P_L - P_V = \frac{4\sigma \; SIN \; \theta}{D'}$$

$$\left(P_L - P_V\right)_{MAX} = \frac{4\sigma \; SIN \; \theta}{D}$$
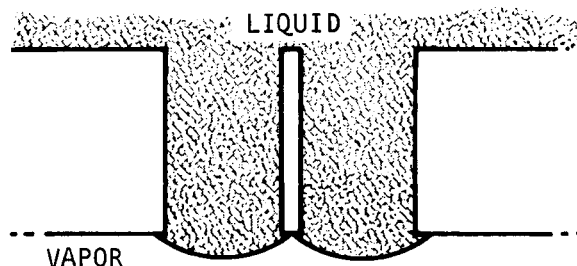
d. LIQUID AT ADJACENT PORE IS ABOUT TO JOIN, ENLARGING D' AND REDUCING THE MAXIMUM PRESSURE THAT CAN BE WITHSTOOD.
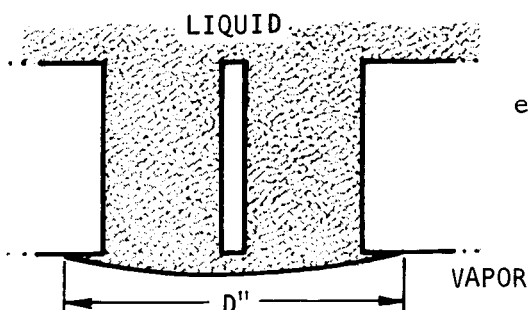
e. BRIDGING HAS OCCURRED. MAXIMUM PRESSURE DIFFERENCE IS REDUCED TO

$$P_L - P_V = \frac{4\sigma \; SIN \; \theta}{D''}$$

A-19950

Figure 3. Liquid Breakthrough Sequence
$0° < \theta < 90°$

Note that this is equal to the result obtained for gas breakthrough with the contact angle between 45 and 90 degrees. The form of this result will be the same for contact angles between 0 and 90 degrees; note that the restraining pressure increases as the angle increases, reaching its maximum value for a 90 degree contact angle. Breakthrough for contact angles greater than 90 degrees has not yet been analyzed.

If the liquid-vapor interface grows from its configuration in Figure 3d the breakthrough pressure will be reduced, and the greater the droplet diameter the lower the breakthrough pressure becomes. What can happen in a porous plate or a wick may be different than what would happen in a single capillary. The reason is shown in Figure 3e where the droplets protruding from adjacent capillaries join, forming a larger drop with a consequently smaller breakthrough pressure. This is believed to be part of the explanation for wicks dripping when they are filled to less than their maximum wicking height.

TASK II: WATER SUBLIMATOR HEAT SINK MODULE

Sublimator Analysis

The sublimation mechanism generally accepted assumes an ice layer next to the porous plate, with the heat transfer rate governing the ice thickness. The ice sublimes at the plate face and freezes at the liquid-ice interface, while the ice block moves continuously toward the porous plate. In the "mixed mode," evaporation takes place from both ice and water surfaces at different pores, due to the varying pore sizes in the porous plate. Published experimental data[1] indicates that the porous plate temperature in this mode is about $32^\circ F$, and that adequate correlation of the heat transfer performance is obtained using this triple point sink temperature. If it is assumed that vaporization takes place at the porous plate face, a pressure drop corresponding to the vapor flow rate fixed by the heat flux may be determined from pressure drop vs flowrate data. This was done for several test modules referred to in Reference 1.

[1] Porous Plate Water Boiler Design Study - Final Report, HSER 3509, Hamilton Standard Division of United Aircraft Corporation, Windsor Locks, Connecticut, May 20, 1965.

From the experimental heat flux, the vapor mass flux is determined from the equation:

$$W = \frac{Q/A}{\Delta H_s}$$

where W = vapor mass flux, $lb_m/hr\ ft^2$

Q/A = Heat flux, $Btu/hr\ ft^2$

ΔH_s = Heat of sublimation of water, Btu/lb_m

By using experimental nitrogen flow rate vs pressure drop curves for free molecule flow given in the referenced report, and by making a simple water vapor correction (given below) derived from the free molecule pressure drop equation, the pressure drop through the porous plate may be determined.

$$\Delta P_{vapor} = \Delta P_{N_2} \left(\frac{R_{vapor}}{R_{N_2}} \right)^{1/2} = 1.25\ \Delta P_{N_2}$$

ΔP_{vapor} = Water vapor pressure drop, lb_{f/in^2}

ΔP_{N_2} = Nitrogen pressure drop, lb_{f/in^2}

R_{vapor} = Water vapor gas constant = 85.8 $lb_f\ ft/lb_m\ ^oR$

R_{N_2} = Nitrogen gas constant = 55.2 $lb_f\ ft/lb_m\ ^oR$

The experimental data and calculated pressure drops are given in Table 2. It is seen that the pressure drops obtained in this manner give pressures on the upstream side of the porous plate of from 1.5 to 11 times the triple point pressure. Since ice was observed in the test units, these high pressures obviously could not have been attained, indicating a deficiency in the assumed mechanism.

One possible explanation is that sublimation takes place not at the porous plate face but at some depth in the pores, thereby shortening the vapor flow length and reducing the pressure drop. However, this would apparently require continuous extrusion of the ice into the pores in order to prevent the ice-vapor interface from receding out of the pores. Normal operating pressures do not appear to be sufficient to accomplish this, and if they were, they might force water breakthrough at those portions of the plate not blocked by ice.

Another possibility is that some type of cycling takes place in which the ice-vapor interface recedes from the pores, at which time water enters and freezes and the process is repeated. This process occurring at different times at various positions on the plate would tend to average out any periodic effects.

A third possible explanation is that some sublimation does indeed take place at the upstream plate face and the sublimed vapor passes through the entire porous plate; while most of the vapor is generated by boiling water which has entered the pores to a sufficient depth to make the vapor pressure drop small. This sounds plausible, but just what would cause the liquid to be restrained at a particular depth, or what would prevent it from breaking through the porous plate when the water feed pressure is greater than the experimentally determined water retention pressure, is not understood at this time.

The importance of the vapor pressure drop problem becomes obvious when a design is considered. If a conservative design is made, assuming vaporization takes place at the plate face and allowing sufficient plate area to limit the upstream pressure to a value below the triple point, the porous plate area is by far the controlling factor in the design, causing the unit to be from 5 to 20 times larger than the heat transfer requirements alone would dictate. Additional analysis and visualization tests, explained below, should provide more insight into this aspect of sublimator operation.

Sublimator Visualization Test

In order to obtain an optimum sublimator design, it is important to understand the mechanism of sublimator operation, and for this reason a

TABLE 2

CALCULATED PRESSURE DROP FOR VAPOR FLOW THROUGH
POROUS PLATES IN SUBLIMATOR

Porous Plate	Q/A Btu/hr ft^2	$P_{ambient}$ psi	T_{pp} °F	W lbm/hr ft^2	ΔP_{vapor} psi
C	470	0.001	33.7	0.385	0.36
	710		34.0	0.582	0.51
	970		34.2	0.795	0.69
	1230		32.0	1.01	0.87
	1475	↓	31.8	1.21	1.03
D	420	~0.002	30.5	0.344	0.131
	475		28.9	0.389	0.140
	580		31.5	0.475	0.156
	610		33.7	0.500	0.162
	690	↓	31.2	0.565	0.168

Q/A = experimental heat flux

$P_{ambient}$ = pressure in vapor passage

T_{pp} = porous plate temperature

W = calculated vapor mass flux

ΔP_{vapor} = calculated vapor pressure drop based upon assumption that vaporization takes place at water side porous plate face

visualization test module has been designed. This unit, shown in Figure 4, consists of a heated plate, finned water passage, porous plate, steam passage, and transparent sides and top, allowing direct observation of the sublimation process. As stated previously, the question of where vaporization takes place, whether in the pores or at the water-side porous plate surface, is critical with respect to vapor pressure drop and ultimately the size of the unit. The test module should aid in resolving this problem as well as such questions as where the ice forms and how the ice layer moves. A visualization test will permit the observation of operation with both rectangular offset and triangular slotted fins, indicating whether or not any ice blockage of the passages occurs, and if so, in which type of fin blockage is more severe. By adjusting the upstream pressure and the heat input, ice or water "breakthrough" will be initiated and observed. This is another critical problem area, for if a significant amount of "breakthrough" occurs the cooling capacity of the water is not realized and the cooling effectiveness (water utilization) is reduced.

Test Specimen Procurement

Four sample porous plates, 3.0 in. in diameter by 0.05 in. thick, were received from Lockheed Missiles and Space Company. These plates are pure nickel and have been fabricated to yield varying porosities. It is planned to run sample evaluation tests to establish a specification for full size sublimator plates of this material. Six porous plates of various characteristics were received from the Clevite Aerospace Division. The plates are pure nickel and are rectangular, 5 in. by 7 in., 0.050 in. thick. Three pieces contain a 20 by 20 mesh 0.007 in. diameter nickel wire reinforcement screen. Use of the reinforcement screen in the parts should inhibit shrinkage during any subsequent brazing operation. One 11-in. square nickel porous plate sample was received from Union Carbide. The thickness is only 0.0072 in. which is considered to be too thin for present construction techniques. Union Carbide claims that they can fabricate the plates in thicknesses up to 0.030 in.

Porous Plate Performance Test Setup

Design of a fixture to be used for sublimation performance testing of various single porous plate modules was previously completed on a company-sponsored research program. The fixture design has been reviewed for improvements to yield greater flexibility and improved data.

VAPOR OUTLET
TO VACUUM

LUCITE TOP
AND SIDES

WATER INLET

FINS

POROUS PLATE

HEATED PLATE
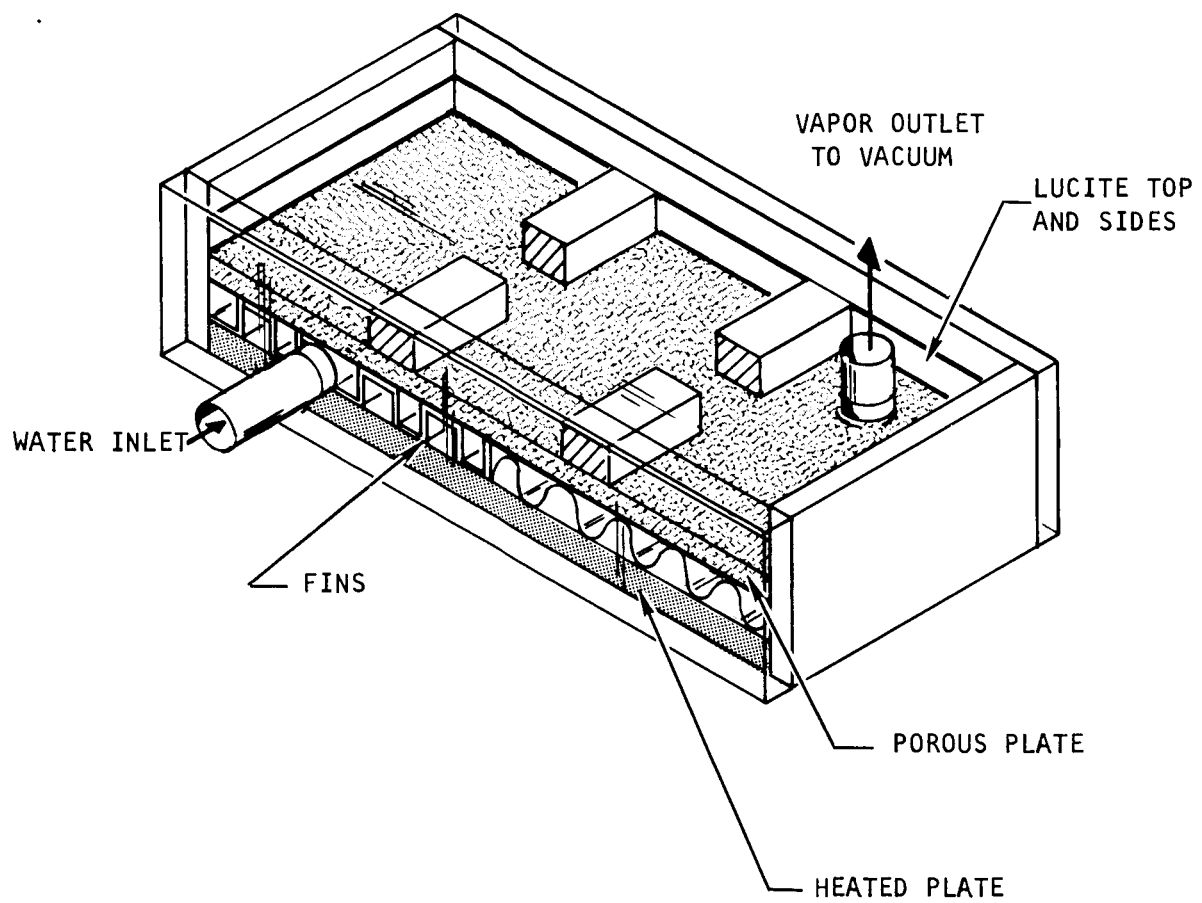
A-19936

Figure 4. Sublimation Visualization Test Unit

Porous Plate Bench Test

A complete set of detailed test instructions for porous plate bench tests was prepared. These tests are described in the AiResearch Engineering Work Order which is shown at the end of this report.

NEXT MONTHLY REPORTING PERIOD

In the next monthly reporting period the following work will be done:

a. Literature review on wicks will be continued

b. Drawings of the wick module heat transfer test section will be completed, and fabrication will be initiated.

c. Analysis of capillary flow and breakthrough will be continued, supported by simple bench scale experiments if required.

d. The sublimator analysis will be continued.

e. The sublimator flow visualization test section will be fabricated and tested.

f. Porous plates now on hand will be subjected to the bench tests described above.

g. Design will be completed and fabrication started on the test fixture for sublimation performance testing of single porous plates.

ENGINEERING WORK ORDER

IF REVISION: Letter ☐ Date_____   Work Order No. __3404-250017-01-0201__

REQUESTED BY J. J. Killackey ⁄ PROJ. 93-5		WORK ASSIGNED TO:	HOURS	MAT'L.
DATE PREPARED 4-26-66		94-5	200	300
REQUIRED COMPLETION DATE 9-30-66				
DATE CLOSED BY				

DESCRIPTION

PRODUCT NAME Porous Plate	CUSTOMER NASA Huntsville
OUTLINE NO. Study Program	SALES ORDER NO. 250017
PACKAGE OR SYSTEM NO. NASA Heat Sink Study	GOV'T. CONTRACT NO. NAS 8-11291

Detail of Work Required: Project Identification Number_____

R E S E A R C H

No Quality Control Surveillance Required

PURPOSE: Testing to be performed per this EWO is part of an over-all program to develop an optimum porous plate sublimator heat sink heat exchanger. A number of different types of porous plates are to be subjected to a series of bench tests to establish plate performance characteristics. Results of these bench tests will be correlated with the performance data to be obtained during subsequent testing. This testing is considered to be exploratory in nature and revisions to the test procedure outlined below will be issued when required.

PROCEDURE: Bench tests are specified below. Engineering will specify the particular tests to be performed for each porous plate sample.

1. **Initial Bubble Point in Alcohol**

Prior to performing this test the plate shall be completely dry. Thoroughly wet the porous plate by soaking it in alcohol for at least 15 minutes. Install the plate in an appropriate fixture and cover the top surface of the plate with a layer of alcohol. The depth of the alcohol layer shall not exceed 1/4 in. Slowly pressurize the bottom surface of the plate with nitrogen until the first dynamic bubble passes through the filter and rises through the liquid. The appearance of the first true dynamic bubble is readily recognized since it is followed by a sucession of additional bubbles. Record the pressure (in. Hg) at which the first bubble is observed. If the test is to be repeated, thoroughly re-wet the plate by soaking in alcohol before proceeding with the retest.

COPIES TO: I. G. Austin
            T. E. McAffee
            J. J. Killackey (3)
            R. A. Stone
            P.   Read (5)
            93-5/File

slg   **APPROVALS**   Page 1 of 4

PROJECT ENGINEER   OTHER

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2. <u>Initial Bubble Point in Water</u>

This test shall be performed as specified for alcohol initial bubble point
(item 1) except the plate shall be wetted by the following procedure:

a. Immerse the porous plate in a tank of distilled water.

b. Place the tank in a vacuum chamber and reduce the pressure to about
   10 mm of Hg (do not go below 5 mm of Hg). Leave the porous plate
   soak under vacuum for at least 1/2 hour.

c. The porous plate shall be removed from the water filled tank just
   prior to performing the bubble point test. The tank may be removed
   from the vacuum chamber after 1/2 hour, but the plates must be kept
   immersed until they are ready to be tested.

d. If the test is to be repeated, re-wet the plate by soaking under
   vacuum as specified above.

3. <u>Pore Size Distribution</u>

This test is to be performed immediately following the initial bubble
point test (alcohol and/or water) while the plate is still thoroughly
wetted. The porous plate is to be kept in the test fixture and covered
with a layer of liquid. Increase the nitrogen gas pressure until 80
per cent of the plate surface area is actively bubbling (best visual
estimate). Record the pressure (in. of Hg).

4. <u>Surface Wetability Check</u>

The porous plate shall be completely dry prior to performing this test.
Mount the porous plate in a horizontal position. At 4 approximately
equally spaced locations place a drop of distilled water on the plate
surface. If the plate surface is clean the drops will immediately wick
into the plate. If the plate is contaminated the water droplets will
either slowly soak into the plate or remain on top of the plate. Record
observations and note the approximately time for the water to be absorbed.
If specified, repeat the above test using alcohol, but select 4 locations
that are spaced away from the areas that have been wet with water.

5. <u>Water Retension Pressure</u>

The porous plate shall be completely dry prior to performing this test.
Mount the porous plate in an appropriate fixture and in a horizontal
position. Slowly fill the plenum area on the bottom surface of the porous
plate with water taking care to eliminate any trapped air pockets. After
the plenum has been filled slowly pressurize the water supply until the
first liquid droplet appears on the top surface of the porous plate; record
the liquid breakthrough pressure. Continue to increase the water pressure
until 80 per cent of the plate surface area is covered with water droplets
(best visual estimate). Record the 80 per cent pressure.

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6. Water Permeability

Install the porous plate in an appropriate fixture and mount the assembly
in a horizontal position. Flow distilled and filtered water throug the
plate as noted below. Care should be taken to obtain a pressure reading
in which all liquid head effects are accounted for. Before recording the
flow verify that the inlet face of the porous plate is fully exposed to
the flow and that there are no trapped air pockets in the inlet manifold.
Test flows shall be as follows:

Water Flow, cc per min per in^2	1, 3, 5, 10, and 15 ±5 per cent
Inlet Water Temperature, $^{\circ}F$	Lab Ambient
Discharge Pressure	Lab Ambient

Record the water pressure drop at each flow. The plate flow area shall be
based on the active area not blocked by the test fixture. Caution: Do
not exceed a pressure differential of 20 in. of Hg across the porous
plate unless directed by Engineering.

7. Nitrogen Permeability with Discharge to Ambient

The porous plate shall be completely dry prior to performing this test.
Install the plate in an appropriate fixture and flow dry and filtered
nitrogen through the plate as specified below:

Nitrogen Flow, lb per hr ft^2	1, 2, 3, 5, and 7 ±5 per cent
Discharge Pressure	Lab Ambient
Inlet Nitrogen Temperature	Lab Ambient

Record the nitrogen pressure drop and temperature at each flow. The
plate flow area shall be based on the active flow area not blocked by
the test fixture. Caution: Do not exceed a pressure differential of
20 in. of hg across the porous plate unless directed by Engineering.

8. Nitrogen Permeability with Discharge to Vacuum

This test shall be as specified for nitrogen permeability with discharge
to ambient (item 7 above) except the nitrogen discharge pressure shall
not exceed 2.0 mm of Hg absolute. Record the actual discharge pressure.

NOTES:

1. Alcohol used in bubble point testing shall be Ethyl Alcohol, 95 per cent.

2. All water used in testing shall be distilled and filtered through a
    1/2 micron absolute filter prior to use.

3. All nitrogen used in testing shall be dry and free on any contaminate
    such as dirt, grit, or oil. The nitrogen shall be filtered through
    a 1/2 micron absolute filter prior to flowing through the test specimen.

4. On each plate tested record the manufacturer, lot number, serial numbe
    and all other pertinent identification information.

5. All testing should be performed in a clean area. When a porous plate is not actually being tested it shall be kept in a polyethylene or nylon·bag at all times. This rule also applies to plates kept in a clean area.

6. Use of a vacuum oven to dry the porous plates shall be rigidly controlled. The oven shall never be used to cure epoxied assemblies or to dry a dirty or contaminated part. When porous plates are being dried other parts or assemblies may be present in the oven provided that the other parts are wet only with water or alcohol.